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MODELING OF A MICROTURBINE WITH PMSM GENERATOR USING MATRIX CONVERTER TECHNIQUE FOR GRID INTERCONNECTION SYSTEM

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ABSTRACT

In this paper, application of Matrix Converter as micro turbine-generator interface converter is addressed. In this way, the interface converter becomes more compact due to omission of dc link capacitor. To investigate the energy production by small scale generators in close proximity to the energy users, integrated into micro-grids. This ultimate form of de-centralised electricity supply, combined with on-site production of heat bears, the promise of substantial environmental benefits. Typically, a Micro-Grid system operates synchronously with the main grid and also has the ability to operate independently from the main power grid in an islanded mode. Distributed renewable energy generators including solar, wind in association with batteries and main grid supply power to the consumer in the Micro-Grid network. MICROGRID is a relatively new concept in the electric power distribution. In a Micro-grid, a cluster of loads and micro-sources operate as a single controllable system to provide power and heat in their local area. The capability of adding a number of smaller generation technologies, such as wind, fuel cells, gas turbines, batteries, ultra-capacitors, and flywheels, makes the Micro-grid a very promising option for on-site power generation by the end-users. It is shown by the simulation results that by using matrix converter, quality of the output voltage is enhanced the matrix converter is reduced the THD value is increased.

KEYWORDS: Matrix Converter (MC), Micro, Grid Systems, Micro, Turbine, Generator

INTRODUCTION

In this study, the Oak Ridge National Laboratory (ORNL) is performing a technology review to assess the market for commercially available power electronic converters that can be used to connect micro turbines [5] to either the electric grid or local loads [7]. The intent of the review is to facilitate an assessment of the present status of marketed power conversion technology to determine how versatile the designs are for potentially providing different services to the grid based on changes in market direction, new industry standards, and the critical needs of the local service provider.

In recent years, application of Distributed Generation (DG) sources has increased significantly. Microturbine-Generator (MTG) is well suitable for different distributed generation applications, because it can be connected in parallel to serve larger loads, can provide reliable power and has low-emission. MTGs have the rated power from 30 to 250 kW [9], generating electricity in ac, and they can be installed in isolated conditions or synchronized with the electrical utility. MTGs [3-5] are available as single-shaft or split-shaft units. Single-shaft unit is a high-speed synchronous machine with the compressor and turbine mounted on the same shaft. While, the split-shaft design uses a power turbine rotating at 3000 rpm and a conventional generator connected via a gearbox for speed multiplication. In this paper, the single-shaft structure is considered. Single-shaft MTGs are usually composed of gas turbines, electric power generators, frequency converter [1].

The power converters permit micro-turbine generators, with their non-synchronous [8-10], high frequency output, to interface with the grid or local loads [6]. The power converters produce 50- to 60-Hz power that can be used for local

loads or, using interface electronics, synchronized for connection to the local feeder and/or micro-grid. The power electronics enable operation in a stand-alone mode as a voltage source or in grid connect mode as a current source.

MICROTURBINE MODELING

Power Converter Design Figure 1 shows a general diagram for a micro-turbine generator system followed by a power converter and a filter. The ac/ac power converter essentially converts high frequency ac to 50 or 60 Hz ac. The power converter can also be designed to provide valuable ancillary services to the power grid or micro-grid. These services may include voltage support, sag support, static volt-amp-reactive (VAR) compensation, load following, operating reserve (e.g., spinning or non-spinning), backup supply, and/or start-up power for the microturbine or other local microturbines.

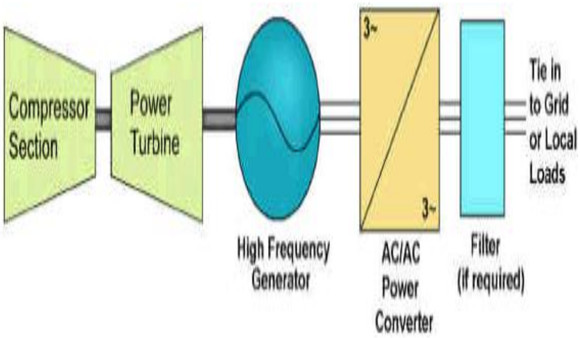

Figure 1: General Microturbine Diagram

Voltage support is common for grid independent operation while load following is used for grid-connected operation. Operating reserve capability may or may not be recognized by the local electricity provider depending on their current tariffs and the capabilities of the microturbine installation. The availability of backup supply and start-up power varies not only by microturbine manufacturer but also by what options may be purchased with the microturbine. For this reason, it will become a topic of discussion in contacts with manufacturers.

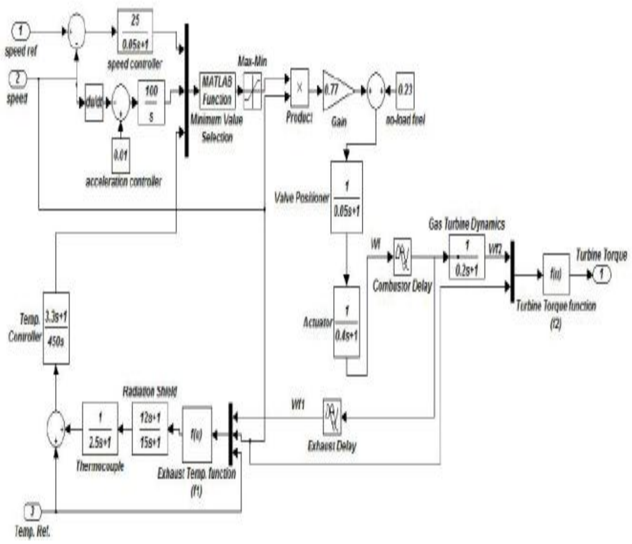

Figure 2: Microturbine Model

There are essentially two types of micro turbine designs. One is a high-speed single-shaft design with the compressor and turbine mounted on the same shaft as the permanent magnet synchronous generator. The generator

generates a very high frequency three phase signal ranging from 1500 to 4000Hz. The high frequency voltage is first rectified and then inverted to a normal 50 or 60 Hz voltage.

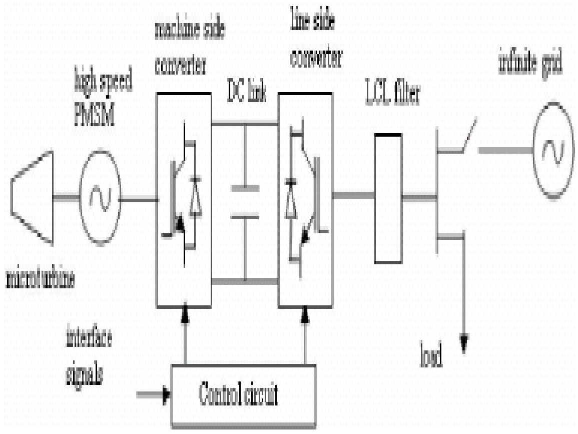

Figure 3: Microturbine Generation System (MTGS)

Another is a split-shaft design that uses a power turbine rotating at 3600 rpm and a conventional generator (usually induction generator) connected via a gearbox. The power electronic interfacing is not needed in this design. Along with the turbine there will be control systems including speed and acceleration control, fuel flow control, and temperature control. A micro turbine can generate power in the range of 25 KW to 500 KW. Figure 3 shows the basic components of microturbine generation systems.

Grid Connected Mode

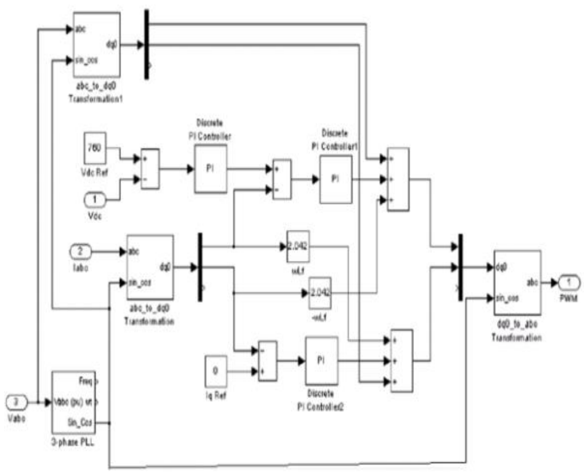

Figure 4: Line Side Converter Control for Grid Connected Mode

The control structure for grid connected mode is shown in Figure 4. The grid-side converter operates as a controlled power source. The standard PI-controllers are used to regulate the grid currents in the d_q synchronous frame in the inner control loops and the dc voltage in the outer loop. It is seen that a PI controller regulates the DC bus voltage by imposing an I_d current component. I_d represents the active component of the injected current into the grid and I_q is its reactive component. In order to obtain only a transfer of active power, the i_q current reference is set to zero. The decoupling terms are used to have independent control of i_d and i_q in. A PLL is used to synchronize the converter with the grid. The philosophy of the PLL is that the difference between grid phase angle and the inverter phase angle can be reduced to zero using PI controller, and thus locking the line side inverter phase to the grid.

Island Operation Mode

In island control mode, no grid exists so the output voltages need to be controlled in terms of amplitude and frequency and thus, the reactive and active power flow is controlled. The control structure for islanding control mode is depicted in Figure 4. It consists of output voltage controller and dc-link voltage controller.

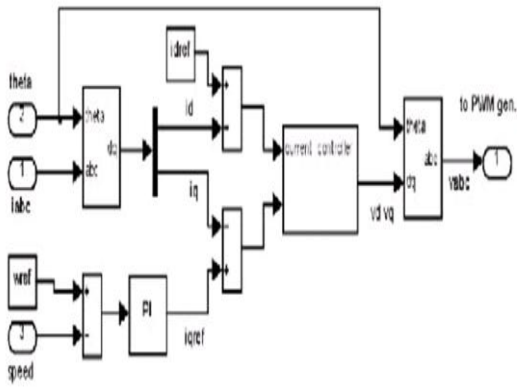

Figure 5: Line Side Converter Control for Islanding Mode

The output voltage controller will control the output voltage with a minimal influence from the shape of the load currents or load transients. A standard PI controller operating in the synchronously rotating coordinate system where v_q is kept to zero is used. The dc-voltage PI controller maintains the dc voltage to the reference. The dc-link voltage controller is acting only when the dc-link is below the reference and it lowers the voltage reference of the main voltage controller in order to avoid inverter saturation. For fast response there is a direct forward connection to the voltage controller output. The frequency regulation has been done using virtual PLL block, which is available in the Simpower Systems.

MATRIX CONVERTER (MC)

MC is an array of controlled semiconductor switches that connects directly the three-phase source to the three phase load. In the other words, MC performs a direct AC/AC conversion. While, AC/AC conversion is conventionally achieved by a rectifier stage, a dc link and an inverter stage. Since, in the MC the switching is performed on sinusoidal waveforms, the output voltage quality can be better than the conventional rectifier inverter structure. Also, there is no dc-link (large energy storage element) in MC. So, the MC is more compact compared to conventional AC/AC converters. A common matrix converter structure consisting of 3x3 switches is shown in Figure 6.

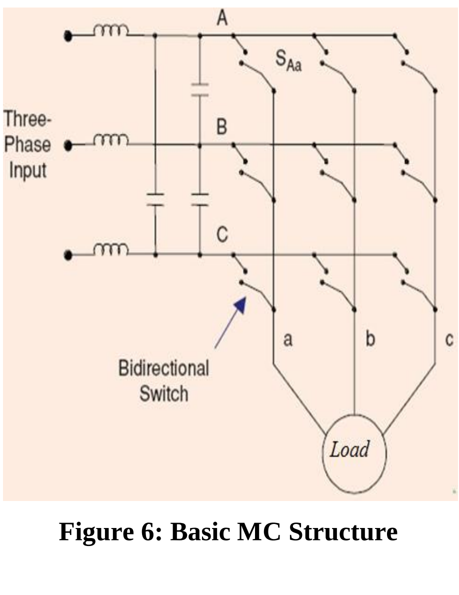

Figure 6: Basic MC Structure

As can be seen, it connects a three-phase voltage source to a three-phase load. The matrix converter requires a bidirectional switch capable of blocking voltage and conducting current in both directions. Unfortunately, there are no such devices currently available, so discrete devices need to be used to construct suitable switch cells. In this paper, the common-emitter back to back structure is used as bidirectional switch.

Normally, the matrix converter is fed by a voltage source and, for this reason; the input terminals should not be short circuited. On the other hand, the load has typically an inductive nature and, for this reason, an output phase must never be opened. Considering Figure 4 and defining the switching function of a single switch as:

$$S_{Kj} = \begin{cases} 1 & switch\, S_{Kj}\ closed \\ 0, & switch\, S_{Kj}\ open \end{cases}$$
$$K = \{A, B, C\} \qquad j = \{a, b, c\} \tag{1}$$

The load and source voltages of Figure 5 with reference to supply neutral are considered as follows:

$$V_o = \begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \quad V_i = \begin{bmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{bmatrix} \tag{2}$$

So, it can be written that

$$\begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{bmatrix} \tag{3}$$

$$V_0 = T.V_i \tag{4}$$

Where T is the instantaneous transfer matrix. In order to derive modulation rules, it is also necessary to consider the switching pattern that is employed. This typically follows a form similar to that shown in Figure 7.

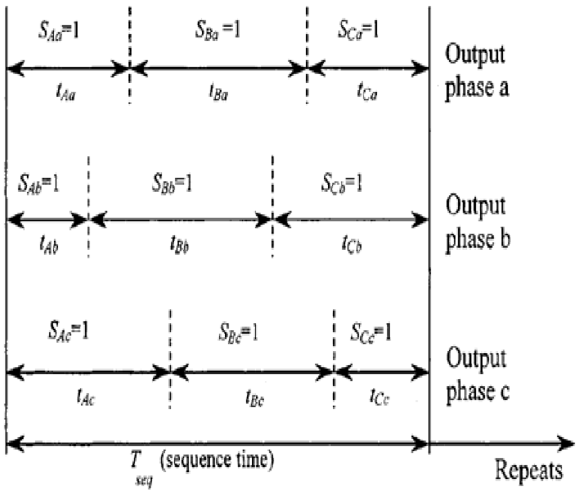

Figure 7: Switching Pattern

By considering that the bidirectional power switches work with high switching frequency, a low-frequency output voltage of variable amplitude and frequency can be generated by modulating the duty cycle of the switches using their respective switching functions. Let $m_{kj}(t)$ be the duty cycle of switch S_{kj}, defined as $m_{kj}(t)=t_{kj}/T_{seq}$, which can have the following values:

$$0 < m_{Kj} < 1 \quad K = \{A, B, C\} \qquad j = \{a, b, c\} \tag{5}$$

The low-frequency transfer matrix is defined by:

$$M(t) = \begin{bmatrix} m_{Aa}(t) & m_{Ba}(t) & m_{Ca}(t) \\ m_{Ab}(t) & m_{Bb}(t) & m_{Cb}(t) \\ m_{Ac}(t) & m_{Bc}(t) & m_{Cc}(t) \end{bmatrix} \tag{6}$$

Some modulation techniques have been presented for MC control. The most popular of them are Venturini, Scalar, and Space Vector Modulation (SVM) methods, the Venturini method is applied for MC control. In this method, switching timing can be expressed in terms of the input voltages and the target output voltages, as follows:

$$m_{Kj} = \frac{t_{Kj}}{T_{seq}} = \frac{1}{3}\left[1 + \frac{2 v_K v_j}{V_{im}^2}\right]$$
$$K = \{A, B, C\} \qquad j = \{a, b, c\} \tag{7}$$

Where V_{im} is the amplitude of source voltages

SIMULATION RESULTS

CASE-I: (Grid Connected Mode)

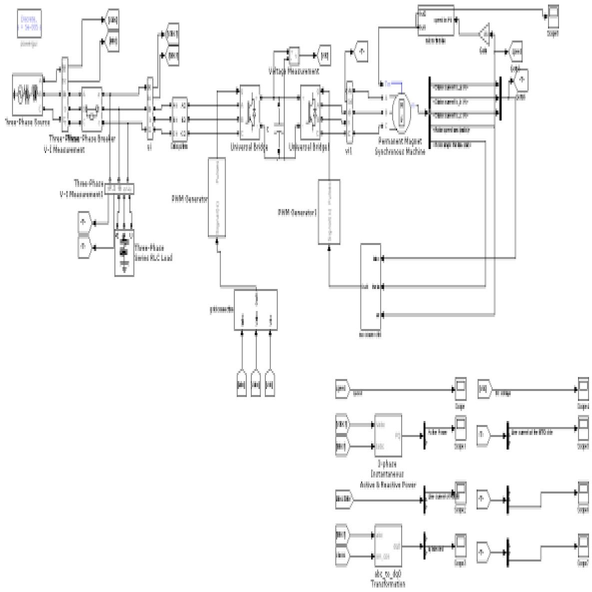

Figure 8: Matlab & Simulink Model of Grid Connected Mode

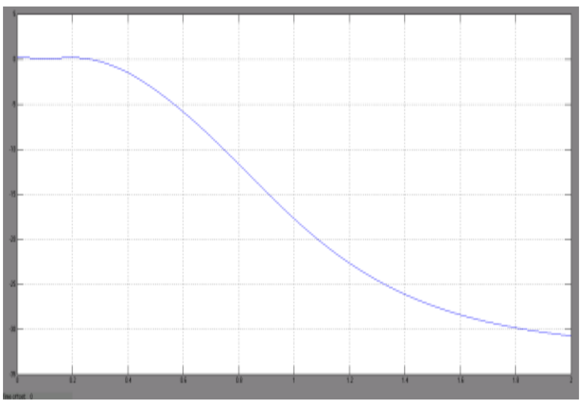

Figure 9: Shows Output Waveform of Torque Characteristics of PMSM

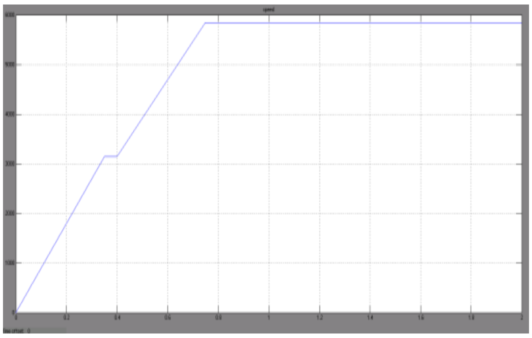

Figure 10: Shows Speed Characteristics of PMSM

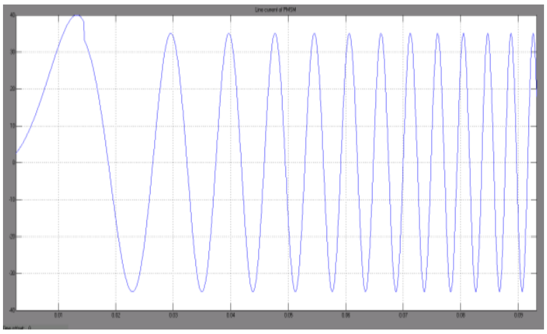

Figure 11: Shows Output Waveform of Stator Current of PMSM

CASE-II: (Island Connected Mode)

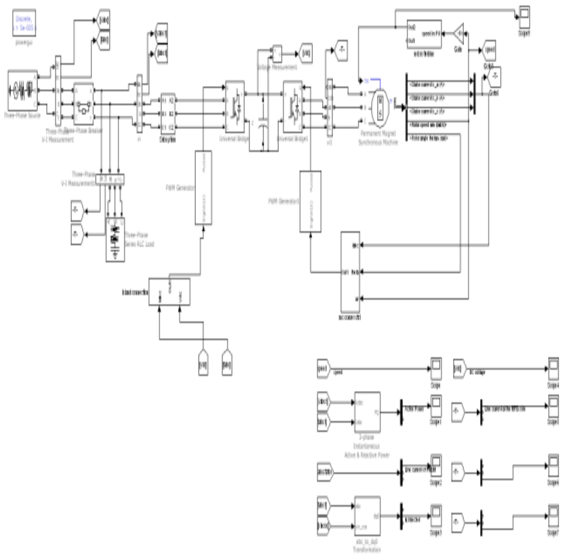

Figure 12: Matlab & Simulink Model of Island Connected Mode

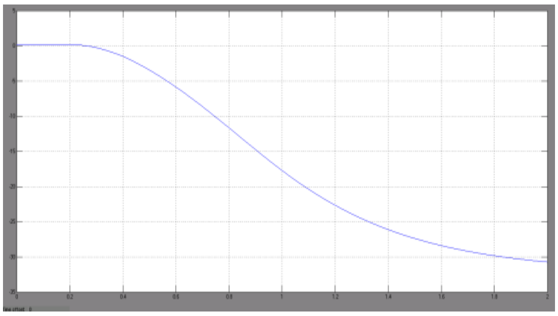

Figure 13: Shows Torque Characteristics of PMSM

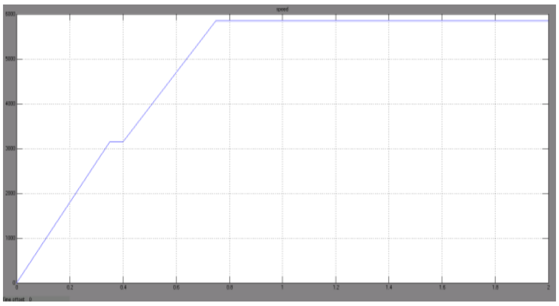

Figure 14: Shows Output Waveform of Speed Characteristics of PMSM

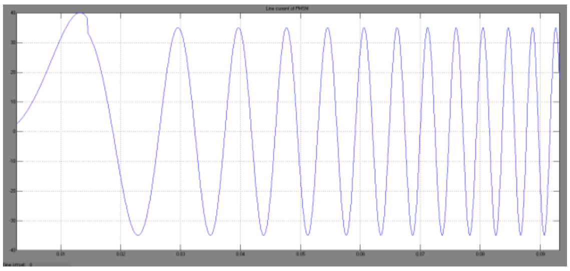

Figure 15: Shows Output Waveform of Stator Current of PMSM

CASE-III: (Matrix Converter Mode)

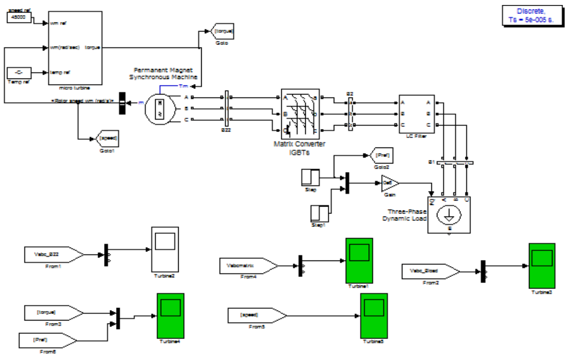

Figure 16: Matlab & Simulink Model of Matrix Converter Mode

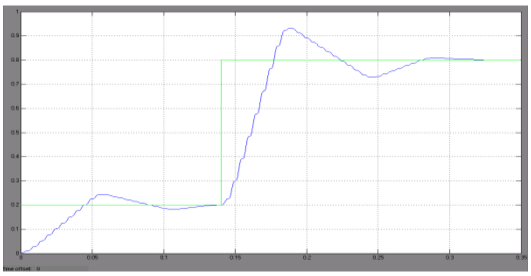

Figure 17: Shows Mechanical Torque Characteristics of PMSM

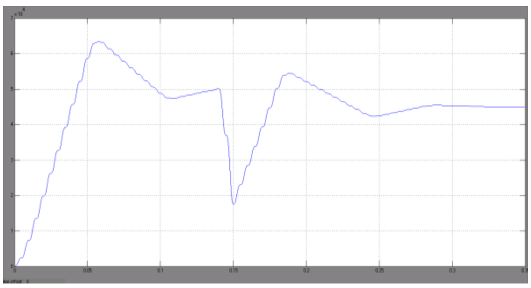

Figure 18: Shows Output Waveform of Speed Characteristics of PMSM

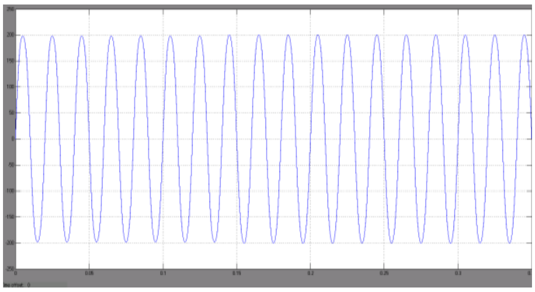

Figure 19: Shows Output Voltage of PMSM

CASE-IV: (Micro-Turbine Mode)

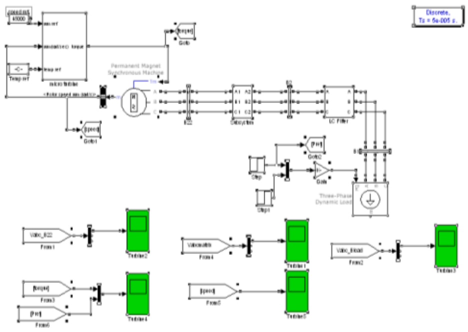

Figure 20: Matlab & Simulink Model of Micro-Turbine Mode

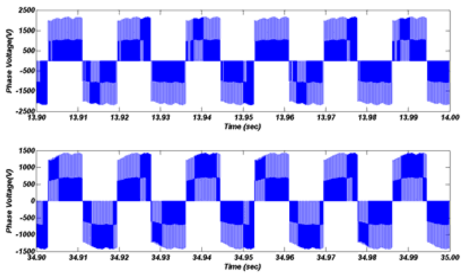

Figure 21: (Matrix Converter Output Voltage Load=0.2pu (Top) Load=0.8 pu (Bottom)

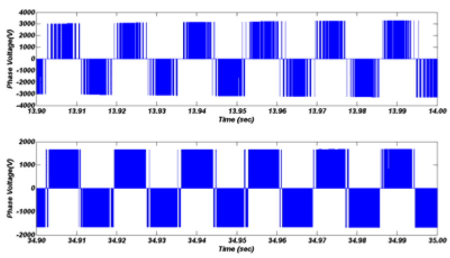

Figure 22: Conventionl Converter Output Voltage Load=0.2 pu(Top) Load=0.2pu(Bottom)

CONCLUSIONS

In this paper, application of the matrix converter as output frequency converter in micro turbine-generator is addressed. Simulation results of MTG using matrix converter demonstrated the ability of MC to deliver a higher quality voltage to the load. The modeling of a single-shaft micro turbine generation modeling generation system suitable for grid connection and islanding operation is presented in this paper**.** THD values (5.5% and 4.5% for 0.2and 0.8 pu loads) using MC are less than the ones in the case of conventional rectifier-inverter structure (7.2% and 6.5% for 0.2 and 0.8 pu loads). The simulation results demonstrate that the established model provides a useful tool suitable to study and to perform accurate analysis of most electrical phenomena that occur when a micro turbine is connected to the grid or is operated in

islanded mode. . Presented model shows good performance in both grid connected islanding mode of operation.

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